

# Tsunami

A **tsunami** is a series of water waves caused by the displacement of a large volume of a body of water, typically an ocean or a large lake. Earthquakes, volcanic eruptions and other underwater explosions (including detonations of underwater nuclear devices), landslides, glacier calvings, meteorite impacts and other disturbances above or below water all have the potential to generate a tsunami.<sup>[3]</sup>

Tsunami waves do not resemble normal sea waves, because their wavelength is far longer. Rather than appearing as a breaking wave, a tsunami may instead initially resemble a rapidly rising tide, and for this reason they are often referred to as *tidal waves*. Tsunamis generally consist of a series of waves with periods ranging from minutes to hours, arriving in a so-called "wave train".<sup>[4]</sup> Wave heights of tens of metres can be generated by large events. Although the impact of tsunamis is limited to coastal areas, their destructive power can be enormous and they can affect entire ocean basins; the 2004 Indian Ocean tsunami was among the deadliest natural disasters in human history with over 230,000 people killed in 14 countries bordering the Indian Ocean.

The Greek historian Thucydides suggested in 426 BC that tsunamis were related to submarine earthquakes,<sup>[5][6]</sup> but the understanding of a tsunami's nature remained slim until the 20th century and much remains unknown. Major areas of current research include trying to determine why some large earthquakes do not generate tsunamis while other smaller ones do; trying to accurately forecast the passage of tsunamis across the oceans; and also to forecast how tsunami waves would interact with specific shorelines.



## Etymology

*Tsunami warning bilingual sign in Ulee Lheue, Banda Aceh in Acehnese and Indonesian*

The term **tsunami** comes from the Japanese 津波, composed of the two kanji 津 (*tsu*) meaning "harbor" and 波 (*nami*), meaning "wave".

Tsunami are sometimes referred to as **tidal waves**. In recent years, this term has fallen out of favor, especially in the scientific community, because tsunami actually have nothing to do with tides. The once-popular term derives from their most common appearance, which is that of an

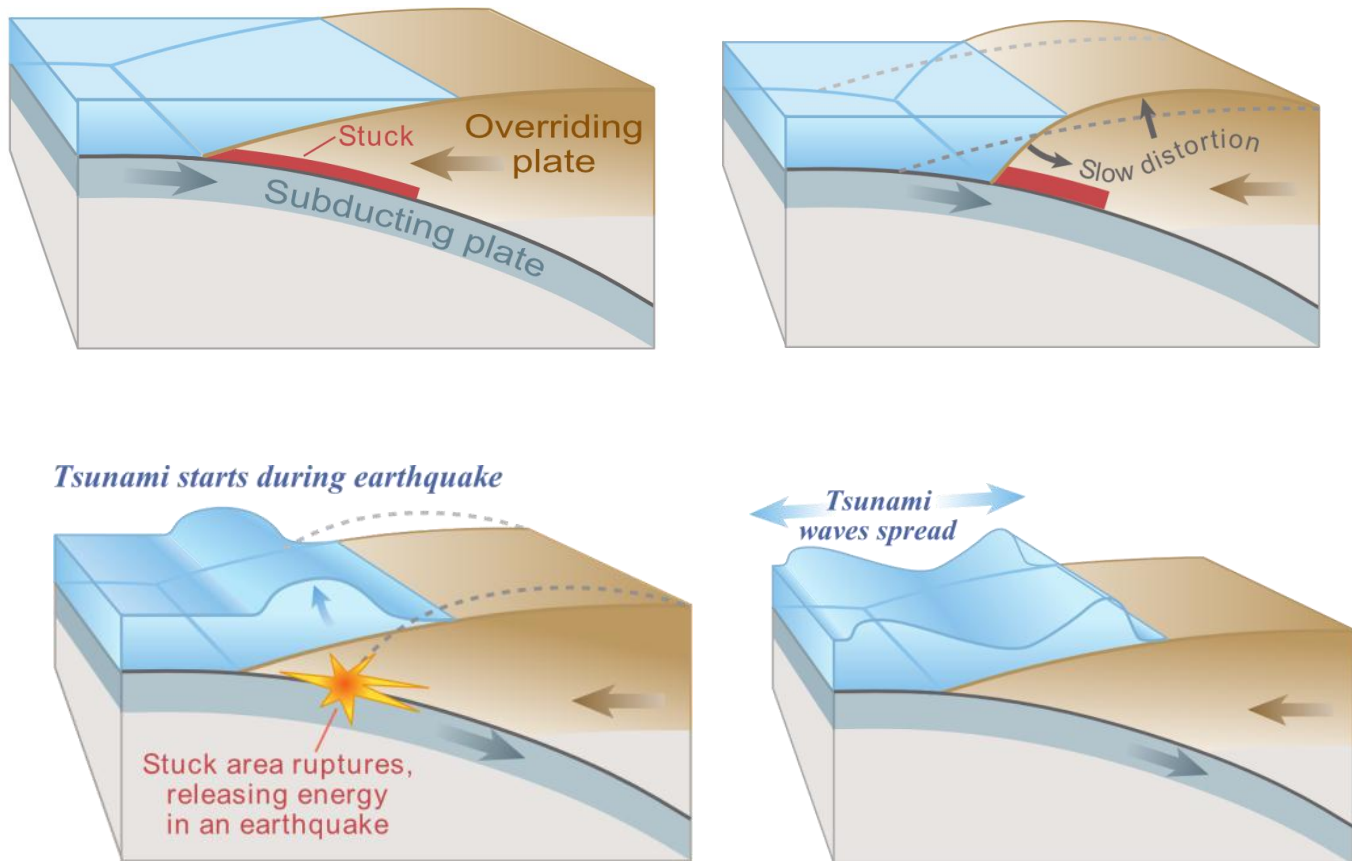
extraordinarily high tidal bore. Tsunami and tides both produce waves of water that move inland, but in the case of tsunami the inland movement of water is much greater and lasts for a longer period, giving the impression of an incredibly high tide. Although the meanings of "tidal" include "resembling"<sup>[8]</sup> or "having the form or character of"<sup>[9]</sup> the tides, and the term *tsunami* is no more accurate because tsunami are not limited to harbours, use of the term *tidal wave* is discouraged by geologists and oceanographers.

### Generation mechanisms

The principal generation mechanism (or cause) of a tsunami is the displacement of a substantial volume of water or perturbation of the sea.<sup>[18]</sup> This displacement of water is usually attributed to either earthquakes, landslides, volcanic eruptions, glacier calvings or more rarely by meteorites and nuclear tests.<sup>[19][20]</sup> The waves formed in this way are then sustained by gravity. Tides do not play any part in the generation of tsunamis.

### Tsunami generated by seismicity

Tsunami can be generated when the sea floor abruptly deforms and vertically displaces the overlying water. Tectonic earthquakes are a particular kind of earthquake that are associated with the Earth's crustal deformation; when these earthquakes occur beneath the sea, the water above the deformed area is displaced from its equilibrium position.<sup>[21]</sup> More specifically, a tsunami can be generated when thrust faults associated with convergent or destructive plate boundaries move abruptly, resulting in water displacement, owing to the vertical component of movement involved. Movement on normal faults will also cause displacement of the seabed, but the size of the largest of such events is normally too small to give rise to a significant tsunami.



The energy released produces tsunami waves.

Tsunamis have a small amplitude (wave height) offshore, and a very long wavelength (often hundreds of kilometers long, whereas normal ocean waves have a wavelength of only 30 or 40 metres), which is why they generally pass unnoticed at sea, forming only a slight swell usually about 300 millimetres above the normal sea surface. They grow in height when they reach shallower water, in a wave shoaling process described below. A tsunami can occur in any tidal state and even at low tide can still inundate coastal areas.

On April 1, 1946, a magnitude-7.8 (Richter Scale) earthquake occurred near the Aleutian Islands, Alaska. It generated a tsunami which inundated Hilo on the island of Hawai'i with a 14 metres high surge. The area where the earthquake occurred is where the Pacific Ocean floor is subducting (or being pushed downwards) under Alaska.

Examples of tsunami originating at locations away from convergent boundaries include Storegga about 8,000 years ago, Grand Banks 1929, Papua New Guinea 1998 (Tappin, 2001). The Grand Banks and Papua New Guinea tsunamis came from earthquakes which destabilized sediments, causing them to flow into the ocean and generate a tsunami. They dissipated before traveling transoceanic distances.

The cause of the Storegga sediment failure is unknown. Possibilities include an overloading of the sediments, an earthquake or a release of gas hydrates (methane etc.)

The 1960 Valdivia earthquake ( $M_w$  9.5) (19:11 hrs UTC), 1964 Alaska earthquake ( $M_w$  9.2), 2004 Indian Ocean earthquake ( $M_w$  9.2) (00:58:53 UTC) and 2011 Tōhoku earthquake ( $M_w$  9.0) are recent examples of powerful megathrust earthquakes that generated tsunamis (known as teletsunamis) that can cross entire oceans. Smaller ( $M_w$  4.2) earthquakes in Japan can trigger tsunamis (called **local** and **regional tsunamis**) that can only devastate nearby coasts, but can do so in only a few minutes.

## Tsunami generated by landslides

In the 1950s, it was discovered that larger tsunamis than had previously been believed possible could be caused by giant landslides. Underwater landslides that generate tsunamis are called sciorrucks.<sup>[23]</sup> These phenomena rapidly displace large water volumes, as energy from falling debris or expansion transfers to the water at a rate faster than the water can absorb. Their existence was confirmed in 1958, when a giant landslide in Lituya Bay, Alaska, caused the highest wave ever recorded, which had a height of 524 metres (over 1700 feet). The wave didn't travel far, as it struck land almost immediately. Two people fishing in the bay were killed, but another boat amazingly managed to ride the wave. Scientists named these waves megatsunami.

Scientists discovered that extremely large landslides from volcanic island collapses can generate megatsunamis that can cross oceans.

## Meteotsunamis

Some meteorological conditions, such as deep depressions that cause tropical cyclones, can generate a storm surge, called a meteotsunami, which can raise tides several metres above normal levels. The displacement comes from low atmospheric pressure within the centre of the depression. As these storm surges reach shore, they may resemble (though are not) tsunamis, inundating vast areas of land.<sup>[24]</sup>

### Characteristics



When the wave enters shallow water, it slows down and its amplitude (height) increases.

The wave further slows and amplifies as it hits land. Only the largest waves crest.

Tsunamis cause damage by two mechanisms: the smashing force of a wall of water travelling at high speed, and the destructive power of a large volume of water draining off the land and carrying all with it, even if the wave did not look large.



While everyday wind waves have a wavelength (from crest to crest) of about 100 metres and a height of roughly 2 metres, a tsunami in the deep ocean has a wavelength of about 200 kilometres. Such a wave travels at well over 800 kilometres per hour, but owing to the enormous wavelength the wave oscillation at any given point takes 20 or 30 minutes to complete a cycle and has an amplitude of only about 1 metre. This makes tsunamis difficult to detect over deep water. Ships rarely notice their passage.

The reason for the Japanese name "harbor wave" is that sometimes a village's fishermen would sail out, and encounter no unusual waves while out at sea fishing, and come back to land to find their village devastated by a huge wave.

As the tsunami approaches the coast and the waters become shallow, wave shoaling compresses the wave and its speed decreases below 80 kilometres per hour (50 mph). Its wavelength diminishes to less than 20 kilometres (12 mi) and its amplitude grows enormously. Since the wave still has the same very long period, the tsunami may take minutes to reach full height. Except for the very largest tsunamis, the approaching wave does not break, but rather appears like a fast-moving tidal bore.<sup>[26]</sup> Open bays and coastlines adjacent to very deep water may shape the tsunami further into a step-like wave with a steep-breaking front.

When the tsunami's wave peak reaches the shore, the resulting temporary rise in sea level is termed *run up*. Run up is measured in metres above a reference sea level.<sup>[26]</sup> A large tsunami may feature multiple waves arriving over a period of hours, with significant time between the wave crests. The first wave to reach the shore may not have the highest run up.<sup>[27]</sup>

About 80% of tsunamis occur in the Pacific Ocean, but they are possible wherever there are large bodies of water, including lakes. They are caused by earthquakes, landslides, volcanic explosions, glacier calvings, and bolides.

## **Drawback**

If the first part of a tsunami to reach land is a trough—called a **drawback**—rather than a wave crest, the water along the shoreline recedes dramatically, exposing normally submerged areas.

A drawback occurs because the water propagates outwards with the trough of the wave at its front.

Drawback begins before the wave arrives at an interval equal to half of the wave's period. Drawback can exceed hundreds of metres, and people unaware of the danger sometimes remain near the shore to satisfy their curiosity or to collect fish from the exposed seabed.

### **Scales of intensity and magnitude**

As with earthquakes, several attempts have been made to set up scales of tsunami intensity or magnitude to allow comparison between different events.<sup>[28]</sup>

## **Warnings and predictions**

Drawbacks can serve as a brief warning. People who observe drawback (many survivors report an accompanying sucking sound), can survive only if they immediately run for high ground or seek the upper floors of nearby buildings. In 2004, ten-year old Tilly Smith of Surrey, England, was on Maikhao beach in Phuket, Thailand with her parents and sister, and having learned about tsunamis recently in school, told her family that a tsunami might be imminent. Her parents warned others minutes before the wave arrived, saving dozens of lives. She credited her geography teacher, Andrew Kearney.



In the 2004 Indian Ocean tsunami drawback was not reported on the African coast or any other east-facing coasts that it reached. This was because the wave moved downwards on the eastern side of the fault line and upwards on the western side. The western pulse hit coastal Africa and other western areas.

A tsunami cannot be precisely predicted, even if the magnitude and location of an earthquake is known. Geologists, oceanographers, and seismologists analyse each earthquake and based on many factors may or may not issue a tsunami warning. However, there are some warning signs of an impending tsunami, and automated systems can provide warnings immediately after an earthquake in time to save lives. One of the most successful systems uses bottom pressure sensors, attached to buoys, which constantly monitor the pressure of the overlying water column.

Regions with a high tsunami risk typically use tsunami warning systems to warn the population before the wave reaches land. On the west coast of the United States, which is prone to Pacific Ocean tsunami, warning signs indicate evacuation routes. In Japan, the community is well-educated about earthquakes and tsunamis, and along the Japanese shorelines the tsunami warning signs are reminders of the natural hazards together with a network of warning sirens, typically at the top of the cliff of surroundings hills.<sup>[30]</sup>



The Pacific Tsunami Warning System is based in Honolulu, Hawai'i. It monitors Pacific Ocean seismic activity. A sufficiently large earthquake magnitude and other information triggers a tsunami warning. While the subduction zones around the Pacific are seismically active, not all earthquakes generate tsunami. Computers assist in analysing the tsunami risk of every earthquake that occurs in the Pacific Ocean and the adjoining land masses.

irect result of the Indian Ocean tsunami, a re-appraisal of the tsunami threat for all coastal areas is being undertaken by national governments and the United Nations Disaster Mitigation Committee. A tsunami warning system is being installed in the Indian Ocean.

Computer models can predict tsunami arrival, usually within minutes of the arrival time. Bottom pressure sensors relay information in real time. Based on these pressure readings and other seismic information and the seafloor's shape (bathymetry) and coastal topography, the models estimate the amplitude and surge height of the approaching tsunami. All Pacific Rim countries collaborate in the Tsunami Warning System and most regularly practice evacuation and other procedures. In Japan, such preparation is mandatory for government, local authorities, emergency services and the population.

Some zoologists hypothesise that some animal species have an ability to sense subsonic Rayleigh waves from an earthquake or a tsunami. If correct, monitoring their behavior could provide advance warning of earthquakes, tsunami etc. However, the evidence is controversial and is not widely accepted. There are unsubstantiated claims about the Lisbon quake that some animals escaped to higher ground, while many other animals in the same areas drowned. The phenomenon was also noted by media sources in Sri Lanka in the 2004 Indian Ocean earthquake.<sup>[31][32]</sup> It is possible that certain animals (e.g., elephants) may have heard the sounds of the tsunami as it approached the coast. The elephants' reaction was to move away from the approaching noise. By contrast, some humans went to the shore to investigate and many drowned as a result.

. As the plan, announcement will be available from 2014.<sup>[33][34][35]</sup>

## Mitigation

### *A seawall at Tsu, Japan*

In some tsunami-prone countries earthquake engineering measures have been taken to reduce the damage caused onshore. Japan, where tsunami science and response measures first began following a disaster in 1896, has produced ever-more elaborate countermeasures and response plans.<sup>[36]</sup> That country has built many tsunami walls of up to 4.5 metres (15 ft) to protect populated coastal areas. Other localities have built floodgates and channels to redirect the water from incoming tsunami.

However, their effectiveness has been questioned, as tsunami often overtop the barriers. For instance, the Okushiri, Hokkaidō tsunami which struck Okushiri Island of Hokkaidō within two to five minutes of the earthquake on July 12, 1993 created waves as much as 30 metres (100 ft) tall—as high as a 10-story building. The port town of Aonae was completely surrounded by a tsunami wall, but the waves washed right over the wall and destroyed all the wood-framed structures in the area. The wall may have succeeded in slowing down and moderating the height of the tsunami, but it did not prevent major destruction and loss of life.<sup>[37]</sup>



## Questions

1. Define 'tsunami' and explain why it is often called a 'tidal wave'
2. Give a detailed account of how seismic tsunamis are formed.
3. "Tsunami usually originate at convergent plate boundaries". Discuss why this statement is often, but not always, true.
4. Describe in detail how tsunami behaviour changes from deep to shallow water.
5. Give the possible ways in which tsunami may be warned and their effects reduced.